ScienceNews for Students

CHEMISTRY

Here's how hot water might freeze faster than cold

Properties of hydrogen bonds may explain the effect — if it even exists

BY **EMILY CONOVER** JAN 25, 2017 — 7:10 AM EST

Hot water might freeze faster than cold water under certain conditions, some scientists say. Properties of hydrogen bonds could explain how this happens. But not all scientists agree that the effect is even real.

Cold water should freeze faster than hot water. Right? It seems logical. But some experiments have suggested that under the right conditions, hot water can freeze faster than cold. Now chemists offer a new explanation for how this might happen.

What they don't do, however, is confirm that it actually does occur.

The speedier freezing of hot water is known as the Mpemba effect. If it happens, it would be only under certain conditions. And those conditions would involve the bonds that link up neighboring water molecules. A team of chemists describe these potential unusual freezing properties in a paper published online December 6 in the *Journal of Chemical Theory and Computation*.

Their paper has not, however, convinced everyone. Some skeptics argue that the effect just isn't real.

People have described quick-freezing of hot water since the early days of science. Aristotle was a Greek philosopher and scientist. He lived in the 300s B.C. Back then, he reported observing hot water freezing faster than cold water. Fast forward to the 1960s. That's when a student from the East African nation of Tanzania, Erasto Mpemba, noticed something strange, too. He claimed that his ice cream turned into a solid faster when it was put into the freezer steaming hot. Scientists soon named the quick-freezing hot-water phenomenon for Mpemba.

No one is sure what might cause such an effect, although plenty of researchers have guessed at explanations. One is related to evaporation. That's the transition of a liquid to a gas. Another has to do with convection currents. Convection occurs when some hotter material in a fluid or gas rises and colder material sinks. Yet another explanation suggests that that gasses or other impurities in water might alter its freezing rate. Still, none of these explanations has won over the general scientific community.

Now along comes Dieter Cremer of Southern Methodist University in Dallas, Texas. This theoretical chemist has used *computer models* to simulate to actions of atoms and molecules. In a new paper, he and his colleagues propose that chemical linkages — bonds — between water molecules could help explain any Mpemba effect.

Explainer: What is a computer model?

(https://www.sciencenewsforstudents.org/article/explainer-what-computer-model)

Unusual links between the water molecules?

Hydrogen bonds are links that can form between hydrogen atoms of one molecule and the oxygen atom of a neighboring water molecule. Cremer's group studied the strengths of these bonds. To do that they used a computer program that simulated how water molecules would cluster.

As water warms, Cremer notes, "We see that hydrogen bonds change." The strength of these bonds can differ based on how the nearby water molecules are arranged. In simulations of cold water, both weak and strong hydrogen bonds develop. But at higher temperatures, the model predicts that a bigger share of the hydrogen bonds will be strong. It seems, Cremer says, "The weaker ones are broken to a large extent."

His team realized that its new understanding of hydrogen bonds might explain the Mpemba effect. As water is warmed, weaker bonds would break. This would cause big clusters of these linked molecules to fragment into smaller clusters. Those fragments might realign to form tiny ice crystals. They could then serve as starting points for the bulk freezing to proceed. For cold water

to rearrange in this way, weak hydrogen bonds would first have to break.

"The analysis in the paper is very well done," says William Goddard. He is a chemist at the California Institute of Technology in Pasadena. But, he adds: "The big question is, 'Does it actually relate directly to the Mpemba effect?'"

Cremer's group noted an effect that might trigger the phenomenon, he says. But those scientists didn't simulate the actual freezing process. They didn't demonstrate that it happens faster when the new hydrogen bonding insights are included. Simply put, Goddard explains, the new study "doesn't actually make the final connection."

Somel scientists have a bigger concern with the new study. Among them is Jonathan Katz. A physicist, he works at Washington University in St. Louis. The idea that warm water might freeze faster than cold water "just makes absolutely no sense," he says. In Mpemba experiments, the water freezes over a period of minutes or hours. As the temperature drops over that period of time, weak hydrogen bonds would reform and molecules would rearrange, Katz argues.

Other researchers also are debating whether the Mpemba effect exists. Scientists have struggled to produce the effect in a repeatable way. For example, one group of scientists measured the time for hot and cold samples of water to cool to zero degrees Celsius (32 degrees Fahrenheit). "No matter what we did, we could not observe anything akin to the Mpemba effect," says Henry Burridge. He is an engineer at Imperial College London in England. He and colleagues published their results November 24 in *Scientific Reports*.

But their study "excluded a very important aspect of the phenomenon," says Nikola Bregović. He is a chemist at the University of Zagreb in Croatia. He says Burridge's study observed only the time to reach the temperature at which water freezes. It did not observe the initiation of freezing itself. And, he points out, the process of freezing is complex and hard to control. That is one reason the Mpemba effect has been so hard to investigate. But, he adds, "I am still convinced that hot water can freeze more quickly than cold water."

Power Words

(for more about Power Words, click here (https://student.societyforscience.org/power-words-aid-stem-literacy))

Aristotle An ancient Greek philosopher who lived during the 300s B.C. He studied many scientific topics, including biology, chemistry, physics and zoology. But science was far from his only interest. He also probed ethics, logic, government and politics — the underpinnings of what would become European culture.

atom The basic unit of a chemical element. Atoms are made up of a dense nucleus that contains positively charged protons and neutrally charged neutrons. The nucleus is orbited by a cloud of negatively charged electrons.

bond (in chemistry) A semi-permanent attachment between atoms — or groups of atoms — in a molecule. It's formed by an attractive force between the participating atoms. Once bonded, the atoms will work as a unit. To separate the component atoms, energy must be supplied to the molecule as heat or some other type of radiation.

chemical A substance formed from two or more atoms that unite (become bonded together) in a fixed proportion and structure. For example, water is a chemical made of two hydrogen atoms bonded to one oxygen atom. Its chemical symbol is H_2O. Chemical can also be an adjective that describes properties of materials that are the result of various reactions between different compounds.

chemistry The field of science that deals with the composition, structure and properties of substances and how they interact with one another. **Chemists** use this knowledge to study unfamiliar substances, to reproduce large quantities of useful substances or to design and create new and useful substances.

computer model A program that runs on a computer that creates a model, or simulation, of a real-world feature, phenomenon or event.

convection The rising and falling of material in a fluid or gas due to uneven temperatures. This process occurs in the outer layers of some stars.

crystal (adj. **crystalline**) A solid consisting of a symmetrical, ordered, three-dimensional arrangement of atoms or molecules. It's the organized structure taken by most minerals. Apatite, for example, forms six-sided crystals. The mineral crystals that make up rock are usually too small to be seen with the unaided eye.

engineer A person who uses science to solve problems. As a verb, *to engineer* means to design a device, material or process that will solve some problem or unmet need.

hydrogen The lightest element in the universe. As a gas, it is colorless, odorless and highly flammable. It's an integral part of many fuels, fats and chemicals that make up living tissues.

Mpemba effect A scientific observation that claims that hot water can, under certain circumstances, freeze more quickly than cold water. The principle is named for a Tanzanian student, Erasto Batholomeo Mpemba. He reported seeing the effect while making ice cream as a 13-year old in 1963.

molecule An electrically neutral group of atoms that represents the smallest possible amount of a chemical compound. Molecules can be made of single types of atoms or of different types. For example, the oxygen in the air is made of two oxygen atoms (O_2), but water is made of two hydrogen atoms and one oxygen atom (H_2O).

oxygen A gas that makes up about 21 percent of the atmosphere. All animals and many microorganisms need oxygen to fuel their metabolism.

physicist A scientist who studies the nature and properties of matter and energy.

simulation (v. **simulate**) A model, often made using a computer, of some conditions, functions or appearance of a physical system. A computer program does this by using mathematical operations that can describe the system and how it might vary in response to various situations or over time.

theory (in science) A description of some aspect of the natural world based on extensive observations, tests and reason. A theory can also be a way of organizing a broad body of knowledge that applies in a broad range of circumstances to explain what will happen. Unlike the common definition of theory, a theory in science is not just a hunch. Ideas or conclusions that are based on a theory — and not yet on firm data or observations — are referred to as **theoretical**. Scientists who use mathematics and/or existing data to project what might happen in new situations are known as **theorists.**

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Journal: H. C. Burridge and P. F. Linden. **Questioning the Mpemba effect: hot water does not cool more quickly than cold (http://www.nature.com/articles/srep37665).** . *Scientific Reports*. Vol. 6, November 24, 2016, p. 37665. doi:10.1038/srep37665.

1719 N Street, NW, Washington, DC 20036-2801
202-785-2255

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